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(54) Abstract Title
Controlling airflow in an internal combustion engine with air assist fuel injectors

(57) An air control method for an internal combustion engine having air assist injectors (66) and an electronically controlled throttle (58,62,63,64) maximises airflow through the injectors (66) while maintaining a range of authority for the electronically controlled throttle. This method maximizes the benefits of fuel atomization while maintaining a desired engine speed in the presence of disturbances.

FIG.1

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FIG.1

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START

DSDRPM = f(BV, AC, ECT, N/D) — 200

SELECT REGISTER f(AC, N/D) — 204

RPMERR = DSDRPM - RPM
RPMERR_A = ROLAV — 208

PERLOAD_ISC =
MAF/ FN35(N) * 29.92/BP — 212

216 — MT OR NEUTRAL ? — Y — desmaf_tmp =
f(DSDRPM) * f(ECT, TIME SINCE START) — 220

N

224 — DESMAF_TMP = f(DSDRPM) *
f(ECT, TIME SINCE START)

226 — DESMAF_LOAD = AC_PPM +
PS_PPM + EDF_PPM

DESMAF_PRE = DESMAF_TMP
+ DESMAF_LOAD — 230

(A)

FIG.2A

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```
           ( A )
            │
            ▼
┌───────────────────────────┐
│     DESMAF_SS =           │
│ DESMAF_PRE/TR_DSDRPM +    │─── 238
│       ISCKAM             │
└───────────────────────────┘
            │
            ▼
┌───────────────────────────┐
│    READ TR_DSDRPM         │─── 242
│    FROM STEP 412          │
└───────────────────────────┘
            │
            ▼
┌───────────────────────────┐
│       CALL AAI            │─── 250
│  MAXIMIZATION ROUTINE     │
└───────────────────────────┘
            │
            ▼
     260                              264
        ╱╲                  ┌───────────────────────────┐
       ╱  ╲       Y         │   IPSIBR = PRMERR_A *      │
      ╱ RPMERR_╲───────────▶│ DESMAF_PRE/DSDRPM *       │
      ╲  A > 0 ╱            │   BG_TMR/TC_OVER          │
       ╲  ?  ╱              └───────────────────────────┘
        ╲╱                              │
         │ N                            │
   268   ▼                              │
┌───────────────────────────┐          │
│   IPSIBR = PRMERR_A *      │          │
│ DESMAF_PRE/DSDRPM *       │          │
│   BG_TMR/TC_UNDER         │          │
└───────────────────────────┘          │
            │◀─────────────────────────┘
            ▼
     280    ╱╲                    282
          ╱    ╲          ┌───────────────────────────┐
         ╱IPSIBR >0╲   Y  │  ISCKAM = ISCKAM + STEP   │
        ╱  AND      ╲────▶│  IPSIBR = IPSIBR - STEP   │
        ╲ ISCKAM <  ╱     └───────────────────────────┘
         ╲ PSIBRM? ╱                   │
          ╲      ╱                      │
            ╲╱                          │
            │ N◀────────────────────────┘
            ▼
     286    ╱╲                    288
          ╱    ╲          ┌───────────────────────────┐
         ╱IPSIBR < 0╲  Y  │  ISCKAM = ISCKAM - STEP   │
        ╱   AND      ╲───▶│  IPSIBR = IPSIBR + STEP   │
        ╲ ISCKAM >   ╱    └───────────────────────────┘
         ╲ PSIBRN?  ╱                   │
          ╲       ╱                      │
            ╲╱                          │
            │ N◀────────────────────────┘
            ▼
       ( RETURN )
```

FIG.2B

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START

AAI_MAX_FLW = f(PERLOAD_ISC) *
(bp/29.875)/FN059 (ACT)

WHEN FN059(ACT) = $\sqrt{(ACT + 460)/560}$

310

AAI_MN_TPFLW = f(ECT)

312

DESMAF_CNTR = DESMAF_SS -
f(PERLOAD_ISC) * bp/29.875/ FN059(ACT)

314

316

DESMAF_CNTR >
AAI_MN_TPFLW AND
DESMAF_CNTR -
AAI_MN_TPFLW <
AAI_MAX_FLW
?

Y

A_DES =
DESMAF_CNTR -
AAI_MN_TPFLW

318

N

320

DESMAF_CNTR >
AAI_MN_TPFLW AND
DESMAF_CNTR -
AAI_MN_TPFLW >
AAI_MAX_FLW
?

Y

A_DES =
AAI_MAX_FLW

322

326

DEETCMA = DESMAF_SS -
A_DES - f(PERLOAD_ISC *
bp/29.875 * FN059(ACT)

N

A_DES = 0

324

ETCPOS = f(DEETCMA)

328

AAI_DES_FST = A_DES *
29.875/bp/FN059(ACT)

330

AAIDTY = f(AAI_DES_FST,
PERLOAD_ISC)

332

AAIDTY = MIN(1 .. AAIDTY)

334

FIG.3

RETURN

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START

SPK_ABS_LIM = MINIMUM OF:
SPK_MBT
SPK_BDL
SPK_MF — 402

TR_ABS = FN766 (SPK_ABS - LIM) — 406

TR_FLEX = FN766 (SA_COLD) — 408

TR_RES_BASE = TR_ABS · TR_FLEX — 410

TR_DSDRPM = TR_ABS · TR_RES — 412

RETURN

FIG.4

START

READ DD — 510

DESMAF_SS = f(DD) — 512

CALL AAI
MAXIMIZATION ROUTINE — 514

RETURN

FIG.5

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FIG.6

FIG.7

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AIR CONTROL SYSTEM

The present invention relates to air control systems for internal combustion engines.

5   Internal combustion engines use fuel injectors to precisely control the amount of fuel inducted into the engine's cylinders. Also, fuel injectors atomize the liquid fuel, increasing the homogeneity of the air and fuel mixture. Air assist injectors are devices that use airflow
10   to enhance the atomization of fuel injected into an engine's cylinder. Air assist injectors may be required on some vehicles where additional fuel vaporization can promote better combustion and lower regulated emissions. Further, the air flowing through the air assist injector can be
15   controlled to maximize the benefit as a function of engine operating conditions.

For example, at low engine operating temperature, fuel atomization can be enhanced by controlling a flow valve to be substantially open, thereby allowing a large airflow
20   through the air assist injectors. On the other hand, air assist injector airflow can be restricted by controlling the flow valve to be substantially closed as the temperature increases to prevent overrunning of the engine. Another example, which can be combined with the previous example, is
25   that the flow valve can be controlled to open proportionally to an engine load, thereby allowing an increasing airflow through the air assist injectors as engine load increases to counteract the decreasing pressure ratio caused by increasing manifold pressure. Such a system is disclosed in
30   U.S. Patent 5,460,148.

The inventor herein has recognized numerous disadvantages with the above approaches. For example, when the engine is operating at a mid-load condition, the airflow through the air assist injectors will not be maximized
35   because the flow valve will be partially restricting the airflow to the air assist injectors. This is due to the valve being open proportionally to engine load. In other

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words, at mid-load, the valve is not fully open. Further,
when the engine is started at a warm temperature, the flow
valve will be restricting the airflow, thus preventing
optimal atomization of the injected fuel, which can cause
5   less than optimal emission control. Another disadvantage is
related to the reliance on the operating temperature of the
engine. For example, as an engine ages, less torque, and
thus less air, may be required to maintain a given speed at
a given temperature due to decreased friction. Thus, if
10   temperature alone is used, the engine may develop an
overrunning condition due to excess air flowing through the
air assist injectors, which is utilized in combustion.

     The present invention provides an air control method
for an internal combustion engine, the engine having a first
15   airflow control valve and air assist injectors. The method
comprises the steps of calculating a minimum total required
airflow based on engine operating conditions, controlling
the first airflow control valve to regulate a first quantity
of airflow through the engine, and controlling a second
20   quantity of airflow through the air assist injectors such
that said first quantity of airflow is greater than a
predetermined value with said predetermined value being
defined as a difference between said total required airflow
and said first quantity, thereby allowing said first airflow
25   control valve to maintain primary control of the engine.

     The first airflow control valve is responsible for the
instantaneous control of the engine. The second airflow
control valve is responsible for providing a gradual
adjustment of the airflow through the air assist injectors.
30   By controlling the second airflow control valve such that
the first airflow control valve is never fully closed, it is
always possible to reject disturbances. This is
particularly true when the first airflow control valve has a
faster response and higher accuracy than the second airflow
35   control valve. Also, this arrangement allows the second
airflow control valve to maximize the air assist injector

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airflow while maintaining the first airflow control valve's
ability to reject disturbances.

An advantage of the above aspect of the invention is
that overrunning of the engine speed is avoided.

5   Another advantage of the above aspect of the invention
is that the fuel atomization is maximized.

Yet another advantage of the above aspect of the
invention is that regulated emissions are minimized.

10   The invention will now be described, by way of example,
with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of an engine incorporating
air assist injectors according to the present invention;

Figures 2A, 2B, 3, 4 and 5 are flow charts of various
15   operations performed by a portion of the embodiment shown
in Figure 1; and

Figures 6-7 are examples of operation according to the
present invention.

20   Internal combustion engine 10 comprising a plurality of
cylinders, one cylinder of which is shown in Figure 1, is
controlled by electronic engine controller 12. Engine 10
includes combustion chamber 30 and cylinder walls 32 with
piston 36 positioned therein and connected to crankshaft 40.
25   Combustion chamber 30 is shown communicating with intake
manifold 44 and exhaust manifold 48 via respective intake
valve 52 and exhaust valve 54. Intake manifold 44 is shown
communicating with throttle body 58 via throttle plate 62.
Primary air control is governed by throttle plate 62.
30   Throttle plate 62 is controlled by an electronic throttle
controller 63. Throttle position of throttle plate 62 is
measured by throttle position sensor 64. Controller 12
provides signal ETCPOS to electronic throttle controller 63
so that airflow is inducted into engine 10 around throttle
35   plate 62 at a rate proportional to the signal ETCPOS.
Intake manifold 44 is also shown having air assist injector
66 coupled thereto for delivering liquid fuel in proportion

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to the pulse width of signal fpw from controller 12. Fuel
is delivered to fuel injector 66 by a conventional fuel
system including fuel tank 68, fuel pump (not shown), and
fuel rail 67.

5   Conventional distributorless ignition system 88
provides ignition spark to combustion chamber 30 via spark
plug 92 in response to spark advance signal SA from
controller 12.

         Catalytic type exhaust gas oxygen sensor 16 is shown
10   coupled to exhaust manifold 48 upstream of catalytic
converter 20. Sensor 16 provides signal EGO to controller
12 which converts signal EGO into a two-state signal. A
high voltage state of converted signal EGO indicates exhaust
gases are rich of a desired air/fuel ratio and a low voltage
15   state of converted signal EGO indicates exhaust gases are
lean of the desired air/fuel ratio. Typically, the desired
air/fuel ratio is selected as stoichiometry which falls
within the peak efficiency window of catalytic converter 20.

         Bypass passageway 94 is shown coupled between throttle
20   body 58 and air assist injector 66 via solenoid bypass valve
97. Controller 12 provides pulse width modulated signal
AAIDTY to solenoid bypass valve 97 so that airflow is
inducted into engine 10 at a rate proportional to the duty
cycle of signal AAIDTY.

25   Controller 12 is shown in Figure 1 as a conventional
microcomputer including: microprocessor unit 102,
input/output ports 104, read only memory 106, random access
memory 108, and a conventional data bus. Controller 12 is
shown receiving various signals from sensors coupled to
30   engine 10, in addition to those signals previously
discussed, including: measurements of inducted mass air
flow (MAF) from mass air flow sensor 110 coupled to throttle
body 58; engine coolant temperature (ECT) from temperature
sensor 112 coupled to cooling sleeve 114; intake air
35   temperature (ACT) from temperature sensor 113 coupled to
throttle body 58, a profile ignition pickup signal (PIP)
from Hall effect sensor 118 coupled to crankshaft 40.

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Referring now to Figures 2, 3, and 4, the subroutines
executed by controller 12 for controlling engine idle speed
are now described. Referring first to Figure 2, desired
idle speed signal DSDRPM is first calculated as a function
5   of battery voltage BV, air conditioner enable signal AC,
engine coolant temperature ECT and the neutral or drive
transmission signal N/D (step 200). One of four storage
registers is selected in step 204 as a function of signal
AC, and signal N/D. More specifically, the following
10   registers are selected: a first register is selected if the
transmission is not in drive and the air conditioner is on;
a second register is selected if the air conditioner is off
and the transmission is in drive; a third register is
selected if the transmission is in neutral and the air
15   conditioner is on; and a fourth register is selected if the
transmission is in neutral and the air conditioner is off.

Idle speed error signal RPMERR is calculated in step
208 by subtracting an indication of engine speed signal rpm
from desired idle speed signal DSDRPM. Signal RPMERR_A is
20   also generated which is a rolling average of signal RPMERR
with exponential smoothing. During step 212, an estimate of
the pressure ratio across bypass valve 97 is provided. More
specifically, signal PERLOAD_ISC is calculated by dividing a
value (FN35) related to the peak air charge at wide open
25   throttle into signal MAF. The resulting quotient is then
multiplied by the ratio of 29.92 to barometric pressure BP.

If the vehicle has a manual transmission (MT) or an
automatic transmission which is in neutral (step 216),
desired air flow signal DESMAF_TMP is generated in step 220
30   as follows. A function of desired idle speed (DSDRPM) is
multiplied times a function of engine coolant temperature
(ECT) and time since engine start. On the other hand, if
the answer to step 216 is negative, signal DESMAF_TMP is
generated in step 224 as follows. A function of desired
35   idle speed DSDRPM is multiplied by another function of
engine coolant temperature (ECT) and the time since start.

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Correction factor DESMAF_LOAD for desired mass air flow at various loads is generated during step 226. More specifically, signal DESMAF_LOAD is generated by summing three estimates of open loop airflow necessary to idle
5   engine at a given speed, signal AC_PPM when the air conditioner is on, signal PS_PPM when power steering is employed, and signal EDF_PPM when a cooling fan is activated (step 226). Open loop prediction of desired air flow (signal DESMAF_PRE) is generated during step 230 by adding
10   previously calculated signal DESMAF_TMP and signal DESMAF LOAD.

Open loop prediction of desired air flow (signal DESMAF PRE) is corrected by signal TR_DSDRPM which is generated from the subroutine described later herein with particular
15   reference to Figure 4. In general, signal TR_DSDRPM provides a correction to the open loop desired air flow and corresponding open loop bypass throttle position of bypass valve 97. This correction preventing any initial drop in idle speed which would otherwise occur upon commencement of
20   idle speed control under conditions when ignition timing is being retarded for rapid converter warm up.

Desired mass air flow DESMAF_SS is generated by adding signal ISCKAM, a learned adaptive integral term, to signal DESMAF_PRE and then dividing the sum by signal TR_DSDRPM. .
25   After TR_DSDRPM is read from the routine described later herein with particular reference to Figure 4 (step 242), the air assist injector maximization routine is called (step 250), which calculates the signals ETCPOS and AAIDTY as described later herein with particular reference to Figure
30   3.

If the rolling average of the engine speed error signal (RPMERR_A) is positive (step 260), then integral error term IPSIBR is generated as shown in the following equation:

35        $IPSIBR = RPMERR\_A * DESMAF\_PRE/DSDRPM * BG\_TMR/TC\_OVER$

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where: BG_TMR is the background loop time; and TC_OVER
is a calibratable time constant for overspeed.

On the other hand, when signal RPMERR_A is negative,
5   the integral error term is calculated by the following
equation:

IPSIBR = RPMERR_A * DESMAF_PRE/DSDRPM * BG_TMR/TC_UNDER
where: TC_UNDER is a calibratable time constant for
10 underspeed.

When integration term IPSIBR is positive and adaptive
air flow corrections ISCKAM are less than minimum clip value
PSIBRN (step 280), air flow corrections ISCKAM and integral
15 term IPSIBR are generated by the equations shown in Step 282
as follows:

ISCKAM = ISCKAM (previous) + STEP
IPSIBR = IPSIBR (previous) - STEP
20   where: STEP is a calibratable step size.

When integral term IPSIBR is negative and air flow
correction term ISCKAM is greater than minimum clip PSIBRN
(step 286), air flow correction terms ISCKAM and integral
25 term IPSIBR are generated by the equations shown in Step 288
as follows:

ISCKAM = ISCKAM (previous) - STEP
IPSIBR = IPSIBR (previous) + STEP
30

Referring now to Figure 3, according to the present
invention, a subroutine for controlling the distribution of
air controlled by throttle plate 62 and bypass valve 97 is
now described. Maximum airflow possible through the air
35 assist flowpath (AAI_MAX_FLW) is calculated from a function
of PERLOAD_ISC, barometric pressure BP, and ACT (step 310).
Next, the minimum desired throttle mass flow to maintain an

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idle speed control range of authority (AAI_MN_TPFLW) for electronic throttle controller 63 is calculated as a function engine coolant temperature (ECT) (step 312). The range of authority represents the amount of airflow

5 necessary for the idle speed control system to reject disturbances. For example, it is undesirable for throttle plate 62 to be completely closed and all of the air necessary to create the desired torque being supplied through the air assist injectors. It is undesirable because

10 if a load is suddenly removed, such as for example the air conditioning compressor, the engine will experience a rise in engine speed because bypass valve 97 cannot react quick enough. In step 314, the desired airflow around throttle plate 62 and air assist injector 66 (DESMAF_CNTR) is

15 calculated by the equation shown in step 314 as follows:

$$DESMAF\_CNTR = DESMAF\_SS - FN818(PERLOAD\_ISC)$$
$$*BP/29.875*FN059(ACT)$$

20 where: FN818(PERLOAD_ISC) is a function of PERLOAD_ISC and represents flow leaking into the manifold; and

$$FN059(ACT) = \text{square root} ((ACT+460)/560).$$

25 When, DESMAF_CNTR is greater than AAI_MN_TPFLW and DESMAF_CNTR-AAI_MN_TPFLW is less than AAI_MAX_FLW, the desired air assist airflow (A_DES) is set to DESMAF_CNTR-AAI_MN_TPFLW (steps 316 and 318). Otherwise, when DESMAF_CNTR is greater than AAI_MN_TPFLW and DESMAF_CNTR-

30 AAI_MN_TPFLW is greater than AAI_MAX_FLW, the desired air assist airflow (A_DES) is set to AAI_MAX_FLW (steps 320 and 322). Otherwise, desired air assist airflow (A_DES) is set to zero (step 324).

Continuing with Figure 3, in step 326, the routine

35 calculates the amount of air desired around throttle plate 62 as follows:

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$$DEETCMA = DESMAF\_SS - A\_DES - FN818(PERLOAD\_ISC)$$
$$*BP/29.875*FN059(ACT)$$

where: FN818(PERLOAD_ISC) is a function of PERLOAD_ISC
5 and represents flow leaking into the manifold.

Next, in step 328, a desired throttle position (ETCPOS)
is calculated as a function of the amount of air desired
around throttle plate 62 (DEETCMA). The routine then
10 calculates the desired air assist injector airflow
equivalent at standard temperature and pressure
(AAI_DES_FST) as shown in step 328. Next, this value is
converted to a duty cycle (AAIDTY) in step 332 as a function
of the bypass valve versus duty cycle and pressure ratio.
15 More specifically, signal AAIDTY is generated as a function
of signals AAI_DES_FST and signal PERLOAD_ISC. Signal
PERLOAD_ISC was generated as previously described with
reference to step 212. Finally, in step 334, AAIDTY is
clipped to a maximum value of one because it is improper to
20 request a duty cycle greater than one hundred percent.
Referring now to Figure 4, the subroutine for
generating correction signal TR_DSDRPM to correct open loop
desired air flow signal DESMAF_PRE and the corresponding
initial throttle position of bypass throttle valve 96 is now
25 described. An absolute limit of ignition timing (signal
SPK_ABS_LIM) is first selected in step 402 as the minimum
of: ignition timing at maximum engine torque MBT (signal
SPK_MBT), ignition timing associated with borderline knock
(signal SPK_BDL); and ignition timing associated with engine
30 misfire (signal SPK_MF).
The above generated spark absolute limit (SPK_ABS_LIM)
is then converted to torque ratio TR_ABS by conversion
function FN766 during step 406. TR_ABS is the ratio of
indicated torque at SPK_ABS_LIM to the indicated torque at
35 SPK_MBT.In this particular example, conversion function
FN766 is a table of engine output torque as a function of
ignition timing.

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Ignition signal SA_COLD, which is the ignition timing
retard during engine startup, is converted in step 408 to
torque ratio TR_FLEX by function FN766. Torque ratio
TR_FLEX is the flexible torque ratio limit which may be
5   exceeded if required to maintain engine idle speed.
Reserved torque ratio TR_RES_BASE, which could correspond to
a reserve in ignition timing to maintain a desired range of
authority for engine idle speed control via ignition timing,
is then generated in step 410 by taking the difference
10   between torque ratio TR_ABS and torque ratio TR_FELX.

During step 412, the correction value associated with
the torque ratio at desired engine speed (TR_DSDRPM) is
generated by taking the difference between absolute torque
ratio TR_ABS and reserve torque ratio TR_RES.

15   Referring now to Figure 5, the subroutine executed by
controller 12 for controlling total engine airflow during
non-idle conditions are now described. During step 510, a
driver demand signal (DD) is obtained from, for example, a
position sensor measuring a driver pedal mounted in the
20   engine compartment. As would be obvious to one of ordinary
skill in the art and in view of this disclosure, many other
methods may be used to infer a driver demand signal. In
step 512, desired mass air flow (DESMAF_SS) is calculated as
a function of the driver demand signal (DD). As is obvious
25   to one of ordinary skill in the art, DESMAF_SS may also be a
function of many other signals, such as engine speed, engine
torque, desired engine torque, and vehicle speed. Finally,
in step 514, the air assist injector maximization routine is
called to distribute the required airflow between electronic
30   throttle controller 63 and bypass valve 97.

As previously described herein, the air assist
maximization routine will maintain the air flowing through
air assist injectors at a maximum value while still
maintaining a necessary range of authority of the electronic
35   throttle controller to reject disturbances and maintain the
desired idle speed or engine torque. By doing this, optimum

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fuel atomization may be obtained resulting in minimal emissions and reduced engine speed fluctuations.

Referring now to Figures 6 and 7, and in particular to Figure 6, a plot of an example of operation according to the present invention shows the total desired airflow through the engine to maintain a constant engine speed during idle conditions (solid line). A dotted line of this example shows the maximum possible airflow through the air assist injectors (AAI_MAX_FLW), which in this example is equal to the desired airflow through the air assist injectors (A_DES). At time t1, an accessory load for example is applied to the engine, which causes the engine to require more airflow. At time t2, the accessory load is removed. In this example, the engine operating condition, such as, for example, engine coolant temperature, is used to determine that the minimum required airflow, shown by the dash-dot line, will never be below the maximum possible airflow through the air assist injectors (AAI_MAX_FLW). In other words, when this minimum required airflow is greater than or equal to the maximum possible airflow through the air assist injectors (AAI_MAX_FLW), the airflow through the air assist injects can be set at the maximum value. Thus, in this example, the desired airflow through the air assist injectors (A_DES) is set to this maximum value and throttle controller 63 will have a range of authority greater than the difference between the total desired airflow and the desired airflow through the air assist injectors as shown in Figure 6.

Continuing with Figure 7, which shows an example of a situation where the maximum possible airflow through the air assist injectors (AAI_MAX_FLW) is greater than the minimum required airflow for this operating condition. In this example, at time t3 an engine accessory load is removed and then reapplied at time t4. Thus, in this example, the desired airflow through the air assist injectors (A_DES) must be set lower than this minimum required airflow as shown in Figure 7. By doing this, a situation where the

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total required airflow drops below the airflow through the
air assist injectors is avoided. This further avoids a
situation where throttle controller 63 must completely close
throttle plate 62 and rely on bypass valve 97 to maintain
5   engine idle speed by reducing flow through the air assist
injectors.

    The two examples in Figures 6 and 7 show that, by using
a priori knowledge of the minimum required airflow versus
engine operating conditions, it is possible to control the
10 air through the air assist injectors such that throttle
plate 62 will never be more closed that a predetermined
value. This allow throttle plate 62 to maintain primary
control at all times throughout all operating conditions.

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CLAIMS

1. An air control method for an internal combustion engine, the engine having a first airflow control valve (58,62,63,64 and air assist injectors (66), said method comprising:

calculating a minimum total required airflow based on engine operating conditions;

controlling the first airflow control valve (58,62,63,64) to regulate a first quantity of airflow through the engine; and

controlling a second quantity of airflow through the air assist injectors (66) such that said first quantity of airflow is greater than a predetermined value with said predetermined value being defined as a difference between said total required airflow and said first quantity, thereby allowing said first airflow control valve to maintain primary control of the engine.

2. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to an engine speed error signal.

3. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to a desired engine torque signal.

4. A method as claimed in Claim 1, wherein said step of controlling the first airflow control valve further comprises the step of controlling the first airflow control valve to regulate said first quantity of airflow in response to a desired total airflow signal.

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5.   A method as claimed in Claim 1, further comprising the step of adjusting said predetermined value in response to engine operating conditions.

5   6.   A method as claimed in Claim 1, further comprising the step of adjusting said predetermined value in response to engine operating temperature.

7.   An air control method for an internal combustion
10 engine, the engine having a sensor for sensing a speed of the engine, a first airflow control valve and air assist injectors coupled between the engine and a second airflow control valve, said method comprising:
      calculating a minimum total required airflow based on
15 engine operating conditions;
      controlling the first airflow control valve to regulate a first quantity of airflow through the engine;
      controlling the second quantity of airflow through the air assist injectors such that the first quantity of
20 airflow is not less than a predetermined value and a sum of said first quantity and said second quantity is equal to said total required airflow, thereby allowing the first airflow control valve to maintain primary control of the engine.
25

8.   A method as claimed in Claim 7, further comprising the step of adjusting said predetermined value in response to engine operating conditions.

30   9.   A method as claimed in Claim 7, further comprising the step of adjusting said predetermined value in response to engine operating temperature.

10. A control system for an internal combustion engine
35 having air assist injectors (66) comprising:

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a first airflow control valve (58,62,63,64) for
controlling a first quantity of airflow entering the
engine;

a second airflow control valve (97) for controlling a
5   second quantity of airflow passing through the air assist
injectors (66) and then entering the engine;

a controller (12) for controlling said first airflow
control valve to regulate a total quantity of airflow
through the engine, calculating a range of authority
10   necessary for said first airflow control valve to maintain
idle speed control of the engine, and controlling said
second airflow control valve to allow said second quantity
of airflow passing through the air assist injectors (66)
to be a maximum, but less than a difference between said
15   total quantity of airflow and said range of authority.

11.   A system as claimed in Claim 10, wherein said
controller further calculates said range of authority as a
function of engine operating conditions.
20

12.   A system as claimed in Claim 10, wherein said
controller further calculates said range of authority as a
function of engine operating temperature.

25   13.   A system as claimed in Claim 10, wherein said
controller further controls said first airflow control valve
to regulate said first quantity of airflow in response to an
engine speed error signal.

30   14.   A system as claimed in Claim 10, wherein said
controller further controls said first airflow control valve
to regulate said first quantity of airflow in response to a
desired engine torque signal.

35   15.   A system as claimed in Claim 10, wherein said
controller further controls said first airflow control valve

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to regulate said first quantity of airflow in response to a
desired total airflow signal.

    16. An air control method for an internal combustion
5   engine substantially as hereinbefore described with
reference to the accompanying drawings.

    17. An air control system for an internal combustion
engine substantially as hereinbefore described with
10 reference to the accompanying drawings.

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Application No: GB 9909655.4	**Examiner:** Michael Prescott
Claims searched: 1, 7, 10	**Date of search:** 9 August 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G3N (NGBXE, NGBXX, NGE2); G3R (RBN29)

Int Cl (Ed.6): F02D 7/02; F02M 69/08

Other: Online databases: EPODOC, JAPIO, WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	US 5730110 (Chrysler Corporation) whole document	1, 7, 10
X	US 5421311 (Wataya, S - Mitsubishi) whole document	1, 7, 10
X	US 5211148 (Furuya, J et al - Japanese Electronic Control Systems) see embodiments of Fig 4, 7 and 8	1, 7, 10